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High-Performance Heat-Transfer Tubes for AC & R Applications

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The air conditioning and variety of heat exchangers, mainly condensers and evaporators, in which heat transfer takes place between refrigerant and a liquid or between refrigerant and air. The majority of liquid-to-refrigerant heat exchangers are of the shell-and-tube type, which comprise:

- Condensers, with refrigerant condensing in the shell outside the tubes, with the liquid to be chilled flowing in the shell outside the tubes and cooling liquid flowing in the tubes.
- Flooded Evaporators (Coolers), in which the shell and boils on the outer surface of the tubes, with the liquid to be chilled flowing in the tubes.
- Direct Expansion (DX) Evaporators, with refrigerant boiling in the tubes ad chilled liquid flowing n the shell.

Air to-refrigerant heat exchangers are plate fin-and-tubes and air flowing across the coil.

It is the objective of industry world-wide to develop smaller, energy-efficient heat exchangers in order to reduce material and energy costs. One way of achieving this objective is to improve heat transfer by providing surface enhancement both outside and inside the tubes in the forms of external fins or modifying the fins into various shapes and also providing internal ribs, ridges or grooves. There have been several advances in the area of surface enhancement both outsides and inside the tubes over the last two decades.

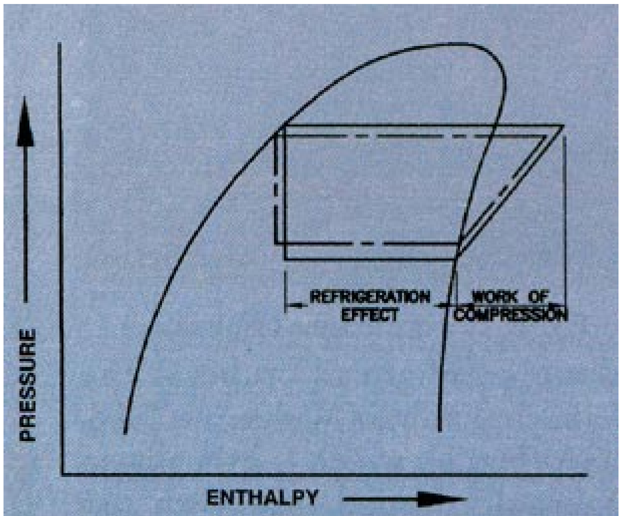
Refrigerant sides film coefficients are usually significantly lower than the liquid (water or brine) side film coefficients. Therefore, it is customary to augment the heat transfer coefficient on the refrigerant sides by producing various types of surfaces on the tubes. A number of high performance tubes are now available for building cost-effective heat exchangers. This article reviews some of these developments elating to heat exchangers with copper tubes and using halocarbon refrigerants.

How High Performance Tubes Increase Efficiency

The use of high performance, enhanced surface tubes in heat exchangers has contributed very significantly to increase in energy efficiency as well as reduction in the size of the cooler and condenser, and a corresponding reduction in the overall cost of refrigerant equipment.

The figure below illustrates the ideal refrigeration cycle of a Flooded Chiller plotted on a pressure - enthalpy (p-h) chart. The cycle (A) represented in continuous lines represents a system in which the condenser and cooler use conventional integrally finned tubes. When these are replaced by enhanced surface tubes, there is a substantial increase in the overall heat transfer coefficient of the heat exchangers, which contributes to reducing the condensing temperature/pressure on the one hand and raising the evaporating temperature/pressure on the one hand and raising the evaporating temperature /pressure on the other. Thus, there is a reduction in head against which he compressor has to do work, and a commensurate reduction in the power input to the compressor. The revised cycle (B) is represented in dotted lines on the p-h-chart. There is also an increase in refrigerating effect, and hence the cooling capacity. Therefore he is an increase in energy efficiency of the Chiller

Over the last two decades, the input power of Centrifugal chillers has come down to around 0.6 kW per ton of refrigeration from 0.9 kW per ton. This has been achieved to a significant extent through the use of improved design of heat exchangers with enhanced surface tubes, apart from other improvements in compressor and system design.



Ideal refrigeration cycle on ph chart

Shell and Tube Condensers

Refrigerant vapour will condense over a tube whose temperature is below the saturation temperature of the vapour. Vapour condensing over a tube may exist either as a wetted film (film condensation) or in droplets (drop condensation). Although drop wise condensation yields a very high heat transfer coefficient, it is difficult to sustain. Hence film wise condensation is considered the more important process of condensation. Surface tension effects are an important phenomenon in enhancement of film condensation. Most refrigerants have low surface tension, which promotes the formation of a thin condensate film on the external profile of the tube. Heat transfer is an inverse function of condensate film thickness and therefore increases with thin condensate films. Hence, short, vertical fins on a horizontal tube will gave a smaller film thickness than on plain tube.

This has led to the development and extensive use of integral externally finned tubes, which were among the very first methods adopted in the design of efficient condensers. Typically, these tubes have 0.75 to 1.5 fins per mm (19 to 40 fins per inch) with fin height of 0.75 to 1.5 mm. A further step was to enhance the inside surface of the finned tube by creating longitudinal or spiral grooves and ridges which create turbulence and augment water side heat transfer. This augmentation promotes turbulence and may also help retard the adverse effect of fouling. A typical example of such "doubly enhanced" tube is the Turbochill® tube of Wolverine Tube, USA (**Fig. 1**), which is basically an externally finned tube with ten internal spiral ribs or ridges. Turbochill® tube has been used in both condensers and in flooded evaporators.

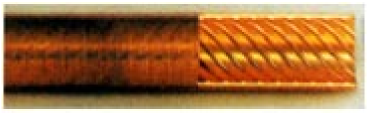


Fig. 1: Turbochill tube (Wolverine)

However, it is also important o promote efficient draining the condensate from the heat transfer surface so that it does not clog the tube surface. Finned tubes experience condensate retention, which tends to restrict their performance. Several enhanced surfaces with complex surface geometries have been developed to promote surface tension- drained condensation such as Thermoexcel-C (**Fig. 3**) by Wolverine Tube, USA.

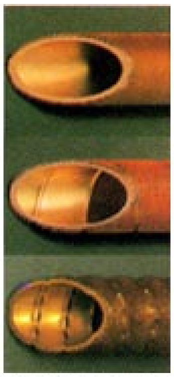


Fig. 2: Thermoexcel -C/CC/CG® tubes (Hitachi)

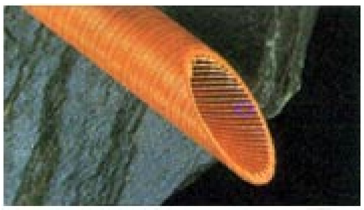


Fig. 3: Turbo C® tube (Wolverine)

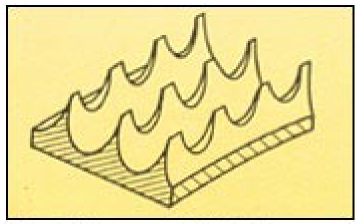


Fig. 4: Thermoexcel-C® (Similar to Turbo – C®)

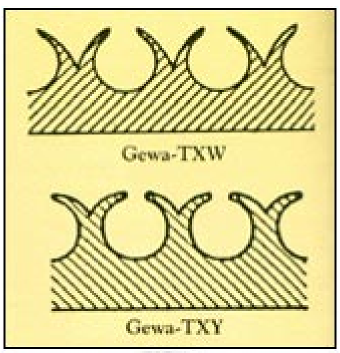


Fig. 5

These surfaces are somewhat similar having knurled spines on the surface (**Fig 4**), which provide a path for condensate drainage. Test result of Turbo C® tube with refrigerant R-12 indicate a heat transfer enhancement of 50 percent over 26 FPI Turbochil® tube. A further development is the Turbo CII® tube which is used in condensers with both R-123 and R-22. A different type of tube is the Gewa-TXV from Wieland Germany, which has a V-shaped fin with a steep angle as shown in **Fig 5**.

Flooded Evaporators

The two most important types of heat transfer regimes in boiling heat transfer are nucleated boiling and convective boiling Nucleate boiling is characterized by vapour bubbles which originate from tiny grooves, holds or cavities in the surface, growing and departing from the heated tube wall. In convective boiling, heat is transferred by convection across a liquid film coating the tube wall and is characterized by evaporation at the vapour - liquid interface of the film.

In flooded evaporators (which are primarily use in Centrifugal and Screw Chillers), the shell-side tube surface can be either of the convective or the nucleate boiling type. The local boiling coefficient is the sum of the nucleate boiling coefficient and the forced-convection effect. With integral finned tubes, heat transfer is primarily due to the forced convection effect and relies on refrigerant velocity to provide two-phase flow enhancement. An example is the Turbochill® tube described above, which has been used in flooded evaporators using R-11.

The external surface can be further modified by cutting, knurling, notching, or rolling a low-finned tube to form new complex fin geometries with significantly higher boiling performances than those of the original tube. Enhanced surface geometries provide substantially higher boiling coefficients than integral finned tubes, because of their higher nucleate boiling effect. An enhanced heat transfer surface helps increase the heat transfer coefficient in the following ways:

- It increases heat transfer area, thereby increasing overall heat transfer rate.
- In flooded coolers, an enhanced refrigerant-side surface provides more and better nucleation points to promote boiling of refrigerant.
- Where the flow of fluid or refrigerant is low, it improves the heat transfer coefficient by increasing turbulence coefficient by increasing turbulence at the surface and mixing the fluid at the surface with fluid away from the surface.

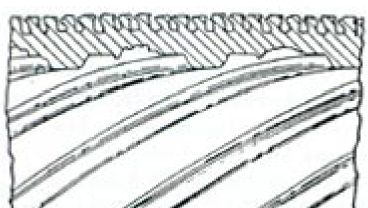


Fig. 6: Cross-section of Turbo-B Tube

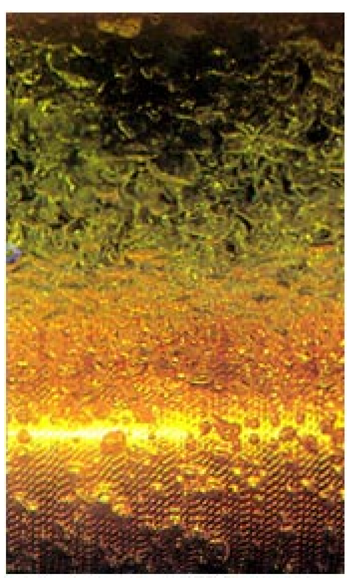


Fig. 7: Refrigerant boiling on the surface of Turbo BII® tube.

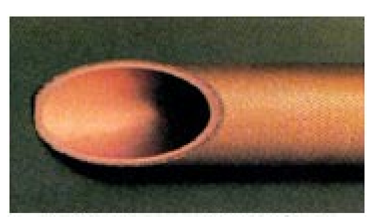


Fig. 8: Thermoexcel TE-HE® tube (Hitachi)

Examples of enhanced surface evaporator tubes are Wieland's GEWA-TX and -TXY (**Fig 5**), Wolverine's Turbo B® (**Fig.6**) and Hitachi's Thermoexcel® -TE, -HEC and -HEG (**Fig. 8**). In Turbo B® tube, the exterior boiling enhancement is produced by raising integral fins, cutting diagonally across these fins, and then rolling the fins to compress them to form mushroom-like pedestals. Re-entrant passageways are thus formed in a rectangular cross-hatch pattern (**Fig 4**) The better boiling performance. The insides (fluid side) surface has multiple spiral bridges somewhat similar to Turbochill®.

Turbo BII® (for R-123, R-22 and R-134a) and Turbo BIII (for R-134a) are recent advances over Turbo B®. According to the manufacturer's catalogue, Turbo BIII®, with R-134a refrigerant, gives an overall heat transfer coefficient ten per cent higher than Turbo BII®.

While renowned tube manufacturers like Wolverine, Hitachi, Wieland, etc. have pioneered variety of patented high performance tubes such as those described above, there are several other manufacturers across the world who have tried to develop similar tubes. Before using such tubes in existing heat exchanger designs, it would be prudent to carry out a small sample bundle of tubes in a refrigerant performance.

Direct Expansion (DX) Evaporators

Enhancements developed for in tube boiling are typically different from external surfaces because the forced convection effect tends to dominate the evaporation process. Factors involved in enhancement are thinning of liquid films and added heat transfer area. Another important consideration is to minimize pressure drop.

Practical manufacturing techniques to form internal fins had not been developed until the late 1960's. Some of the methods adopted around this period for in-tube heat transfer augmentation inside smooth tubes were the use of star inserts, twisted tapes and helical wire inserts. Extruded aluminum star inserts are typically made with five to twelve legs (**Fig 9**). These inserts are installed inside copper tubes, which are then mechanically stretched to create a thermal bond between the legs and the inner tube wall.

Fig. 9: Star Insert tube for DX Coolers.

Twisted steel tapes and helical wire are also used as inserts; the number of twists per unit length can be varied to optimize performance. Helical wire inserts, also referred to as Spring Turbulators, are made of copper or steel wire or rod and are formed to obtain good thermal contact. They should also be shaped to prevent longitudinal movement and vibration inside the tubes due to the flow of refrigerant. These can be installed to improve the performance of existing evaporators and can be removed for cleaning of the tube.

However, the most commonly used method in refrigeration and air conditioning today is the Microfin or internally grooved tube, which significantly increases heat transfer while levying only a small penalty for pressure drop. Microfin tubes typically have 60 to 75 fins, heights from 0.1 to 0.3 mm, and spiral angles of 20 to 30 degrees. These tubes have 1.5 to 2 times he average inside heat transfer coefficient of he same plain tube.

Microfinned tubes augment the heat transfer coefficient relative to a smooth tube by three means :

• Increased convection from the turbulence promoted by the fins.

• More surface area per unit length of tube.

• Increased circumferential wetting of the tube wall by capillary forces at low flow rates.

Commercially available inner grooved tubes include. Thermofin- HEX® tube from Hitachi Cable, Hi-heated® from Kobe Steel and Turbo-DX® from Wolvering Tube (**Fig 10**)

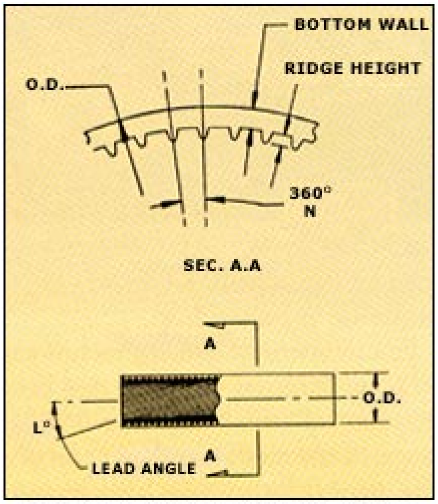


Fig. 10: Inner grooved tube for DX Coolers

Fin & Tube Coils

Microfin or inner grooved tube, as described above, is also extensively used in fin & tube coils which are used as evaporators and aircooled condensers in airconditioners and packaged chillers. Typical evaporating and condensing performance with R-22 shows a 2 to 3 times higher heat transfer coefficient compared to a plain tube, with a pressure drop penalty of less than 10% However, optimum benefits of this tube can be derived only with the use of louvred or slit fins (to provide corresponding air side enhancement) instead of conventional corrugated or sinusoidal fins (**Fig. 11**).

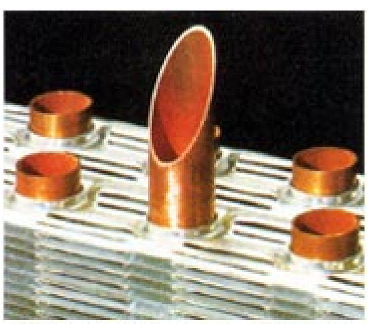


Fig. 11: Slit fin, inner grooved tube oil.

This tube can be easily formed into hairpins for fin & tube foils. It can also be mechanically expanded, allowing a small collapse margin (of about 0.02 mm)for the inner grooves during expansion.

Inner grooved tube is available from a number of manufacturers such as Hitachi Cable (who were the first to develop it in 1977), Kobe Steel, Wolverine Tube and Wieland, to name a few. Outokumpu Copper has developed a crosshatch tube (**Fig.12**) which is claimed to give a performance similar to an inner grooved tube.

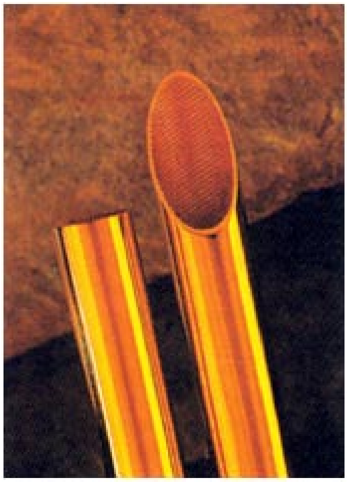


Fig. 12: Crosshatch tube (Outokumpu).

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